

# The Neural Control of Spinal Stability Muscles during Different Respiratory Patterns

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**Abstract.** [Purpose] It is well-known that the muscles of spinal stability also play roles in respiration. The spinal stability muscles are divided into two subgroups, the local muscle group and the global muscle group. Appropriately coordinated activation of muscle groups are recommended for more efficient spinal stability. The indirect method of measuring coordination of muscle groups is the synergist ratio of local muscles to global muscles. The purpose of this study was to investigate the synergist ratios of the spinal stability muscles of different breathing patterns. [Subjects and Methods] Forty healthy subjects performed 4 different breathing patterns and 3 synergist ratios calculated from % maximal voluntary isometric contraction of 2 local group muscles and 3 global group muscles were analyzed. [Results] The results of this study show synergist ratios were consistent among the breathing patterns and there was a consistent muscle reliance pattern of synergist ratios during each breathing pattern. The synergist ratio of extensors stayed around 1. The results were consistent with those of previous studies of spinal stability exercises. [Conclusion] We suggest that different breathing patterns could be used as a component of spinal stability exercises, secondary to the similarities of muscle coordination with spinal stability exercises, commonly used in clinics.

**Key words:** Spinal stability, Synergist ratio, Respiration

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## INTRODUCTION

Spinal stability has been the main topic of rehabilitation research for decades. The spinal stability system consists of three subsystems: a passive subsystem, an active subsystem, and a neural control system. Connective tissues, bones and intervertebral discs are included in the passive subsystem while muscles and tendons are parts of the active subsystem<sup>1, 2)</sup>. Dysfunction of the passive subsystem could cause compensatory muscle activation, controlled by the neural system, for the maintenance of spinal stability<sup>1, 3)</sup>. However, insufficient strength and endurance of muscles, and uncoordinated muscle recruitment result in spinal instability<sup>4)</sup>. Two groups of muscles are considered as spinal stability muscles, the local muscle group and the global muscle group<sup>5)</sup>. The local muscle group is responsible for segmental stability, while the global muscle group generates torque and general spinal stability<sup>6)</sup>. Between the spinal stability muscle groups, the local muscle group activates prior to the global muscle group<sup>7-13)</sup>, to provide a stable base for the activation of the global muscle group<sup>6)</sup>. Therefore, it has been thought that increased local muscle group activation would be more effective for spinal stability<sup>6, 14-16)</sup>. However, sev-

eral studies have showed that the coordinated activation of local and global muscle groups has a greater influence on the spinal stability than individual muscle strength<sup>17, 18)</sup>.

To investigate the coordination of local and global muscle activations, the synergist ratio has been used by several studies<sup>3, 19)</sup>. The synergist ratio is the muscle recruitment pattern, and it is an indirect way of investigating neural control for maintaining spinal stability, such as internal oblique (IO)/rectus abdominis (RA)<sup>3)</sup>. Since the synergist ratio indicates the contribution and the different activation patterns of the local and global muscle groups to spinal stability, the synergist ratio has been used to study the differences between lower back pain subjects and healthy subjects as well as to investigate the muscle recruitment patterns of spinal stability exercises in healthy subjects<sup>3, 19, 20)</sup>. Therefore, the synergist ratio has been suggested as a better and more sensitive measure of motor control, because it can detect altered recruitment patterns and muscle dysfunctions<sup>21)</sup>.

It is well-known that the spinal stability system and respiration system share muscles. The balanced activations of muscles are controlled by the central nervous system during performance of both spinal stability and respiratory tasks<sup>7, 10)</sup>. The muscles used in both spinal stability and respiratory tasks include the diaphragm, transversus abdominis (TrA), intercostal muscles, internal oblique muscle (IO), and pelvic floor muscles (PFM)<sup>7, 8, 22)</sup>. TrA and IO are members of the local muscle group. The external oblique muscle (EO), rectus abdominis (RA), and erector spinae (ES) are well known as accessory muscles of respiration and are members of global muscle group. The mechanism of spinal stability is co-contraction of the muscles to in-

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crease intra-abdominal pressure<sup>23</sup>), and increasing EMG activations of these muscles is indicative of increased respiratory demand<sup>7-10, 22, 24</sup>). However, the synergist ratio of these muscles during respiration has been not studied. The details of the recruitment patterns of these muscles will help to further understanding of motor control mechanism especially when two different tasks are performed by the same muscles. In addition, knowledge about the changed respiratory demands affect the synergist ratios of these muscles would be very useful. Therefore, the purpose of this study was to investigate the synergist ratios of spinal stability muscles in different breathing patterns using the EMG activation levels of spinal stability muscles.

## SUBJECTS AND METHODS

### *Subjects*

Forty healthy volunteers between 18 and 28 years of age participated in this study (19 male, 21 female, 20.75 ± 1.93 years old, height 1.67 ± 0.09 m, weight 61.01 ± 9.62 kg, BMI 21.72 ± 2.37 kg/m<sup>2</sup>). Subjects with a history of low back pain within the last six months, experiencing low back pain at present, musculoskeletal impairments of the lower limbs, or neurological or respiratory pathologies were excluded. Prior to participation, all participants were required to read and sign an informed consent form, in accordance with the ethical standards of the Declaration of Helsinki. The protocol for this study was approved by the local ethics committee of Daegu University.

### *Methods*

All subjects performed 4 different breathing patterns: quiet breathing (QB), combination breathing (CB), diaphragmatic breathing (DB) and respiratory muscle endurance training breathing (RMET). For QB, participants were asked to breathe naturally, as in rest. CB is the breathing pattern in which a pursed lip breathing pattern and diaphragmatic breathing pattern are combined. CB participants were trained to inhale through the nose with outward abdominal motion while reducing upper rib cage motion and to exhale slowly through pursed lips with abdominal contraction<sup>25</sup>). For DB, all participants inhaled through the nose with outward abdominal motion while reducing upper rib cage motion and exhaled through the nose with abdominal muscle contraction<sup>25</sup>). RMET is the breathing technique used for a Spirotiger (Idiag, Spiro Tiger, Switzerland), a partial rebreathing device that ensures normocapnia<sup>26</sup>). The Spirotiger was set to 70% of maximal voluntary ventilation in one minute (MVV) with 50% of vital capacity (VC). MVV and VC were measured using a spirometer (Bionet, Cardiotouch-3000, USA). The respiration ratio of inspiration to expiration was set at 1:2. All breathing patterns were taught by the examiner prior to testing, and adequate practice was allowed for adequate learning. Prior to EMG data collection, each subject was prepared (LAXTHA, LXM 5308) by cleaning the skin with alcohol to reduce impedance<sup>19</sup>). For elimination of skin movement, surface electrodes were attached to the subjects while they were in a standing position. Pairs of Ag/AgCl electrodes (3 M Red Dot) with a

surface diameter of 2 cm and center to center distance of 3 cm were arranged parallel to the fibers over the right side of transversus abdominis/internal oblique (TrA-IO)<sup>5</sup>), external oblique (EO)<sup>5</sup>), rectus abdominis (RA)<sup>5</sup>), erector spinae (ES)<sup>27</sup>), and multifidus (MF)<sup>19</sup>). The placements of electrodes followed those used in previous studies<sup>5, 19, 27</sup>). A ground electrode was placed on the right anterior superior iliac spine (ASIS). Maximum voluntary isometric contraction (MVIC) was used to normalize the EMG data<sup>28</sup>). The MVICs of the muscles were measured in two trials lasting 3 seconds, each followed by a two-minute rest to minimize fatigue<sup>29</sup>). Subjects performed three different isometric exercises against manual resistance<sup>19, 28</sup>). Verbal encouragement was given to ensure maximal effort. Each participant, in a standing position, performed four different breathing patterns in a random order. EMG data were collected for 30 seconds during performance of each breathing pattern, followed by a 1-min rest period. The mean of two trials was used for data analysis. The raw EMG signal was processed using TeleScan™ ver. 3.03. Raw data were filtered using a band-pass filter (20–200 Hz) and a notch filter (60, 120, 180 Hz) included in the software program. EMG data were rectified and smoothed using a root mean square (RMS) algorithm with a 100 neighboring point. The sampling rate was 1,024 Hz and a pre-amplifier gain of 1,250. Three synergist ratios of local muscle to global muscle (TrA-IO/RA, IO/EO, MF/ES) were calculated using %MVIC of each muscle. The analyses of the synergist ratios were performed in 2 areas: among the synergist ratios of each breathing pattern and among the breathing patterns of each synergist ratio. The differences among synergist ratios would indicate a different muscle reliance pattern for performing each breathing pattern, while the differences among the breathing patterns would show changes in the synergist ratio due to the demands imposed on different muscles by breathing patterns change. One-way ANOVA using PASW Statistics ver. 18 was performed to examine the differences among synergist ratios and among the breathing patterns. Tukey's multiple comparisons procedure was used for determination of the post hoc differences in levels of CB, DB, and RMET from QB. Statistical significance for all tests was accepted at  $p < 0.05$ .

## RESULTS

Table 1 shows the mean % MVIC and standard deviations of each muscle in the 4 different breathing patterns. During QB every muscle demonstrated the lowest %MVIC. During RMET, each muscle showed the highest %MVIC. Between CB and DB, the abdominal muscles (TrA-IO, EO and RA) showed higher activations in DB than in CB, while % MVICs of extensors (ES and MF) were higher in CB than in DB. Table 2 shows the synergist ratio of each breathing pattern. There were no significant differences among the breathing patterns of each of the synergist ratios ( $p > 0.05$ ). MF/ES was maintained around 1 the among breathing patterns. Table 2 also shows differences among the synergist ratios of each breathing pattern. TrA-IO/RA was the highest followed by TrA-IO/EO, and MF/ES was the lowest. This

**Table 1.** % MVIC of each muscle in the four different breathing patterns

	QB	CB	DB	RMET
TrA-IO	8.93 ± 7.3	11.86 ± 10.56	14.15 ± 11.76	18.19 ± 12.38
EO	3.25 ± 1.39	4.63 ± 2.32	5.16 ± 2.59	6.83 ± 3.98
RA	2.13 ± 1.02	2.47 ± 1.20	2.56 ± 1.17	3.08 ± 1.49
ES	2.96 ± 1.33	3.46 ± 1.42	3.45 ± 1.55	4.99 ± 2.13
MF	3.14 ± 1.51	4.24 ± 1.99	3.71 ± 1.70	4.56 ± 1.75

**Table 2.** Mean ± SD of synergist ratios of the four different breathing patterns

	QB	CB	DB	RMET
TrA-IO/RA	5.01 ± 4.32	5.71 ± 5.39	6.69 ± 6.66	6.95 ± 5.69
TrA-IO/EO	2.78 ± 1.84	2.63 ± 13.57	2.77 ± 1.51	2.90 ± 1.69
MF/ES	1.23 ± 0.82	1.36 ± 0.75	1.21 ± 0.68	1.08 ± 0.65

muscle reliance pattern was consistent across the breathing patterns. The difference between TrA-IO/RA and TrA-IO/EO in each breathing pattern was significant ( $p < 0.05$ ). Also, the differences between TrA-IO/EO and MF/ES in each breathing pattern were significant ( $p < 0.01$ ).

## DISCUSSION

This study investigated the synergist ratios of spinal stability muscles of different breathing patterns. To the best of our knowledge, there is a very limited number of studies which have investigated the synergist ratios of spinal stability muscles in different breathing patterns. Therefore, in this study comparisons are performed with the studies in which different spinal stability exercises were analyzed. In this study, statistical analyses were performed in 2 areas: synergist ratios of each breathing pattern, for the muscle reliance pattern; and comparison across the breathing patterns of each synergist ratio, for the effects of task demand changes. Most other studies have performed comparisons only among synergist ratios, not among different task demands. Therefore, the comparisons with other studies of the differences with task demand change were limited to the tendency of differences from previous studies.

We drew three conclusions from the results of this study, regarding the synergist ratios of different breathing patterns. First, the synergist ratio of local muscles to global muscles does not change as the task demand changes (average respiratory rate of RMET was 34 times/min, while it was 10 times/min for the other breathing patterns) (Table 2). The reason for this consistent synergist ratio seems to be both global and local muscle activation levels change together as the task demand changes (Table 1)<sup>7-10, 22, 24</sup>. This finding is consistent with previous studies<sup>3, 19, 30, 31</sup>, and supports the evidence that no specific muscle contributes more than other muscles to meet the demand of a task<sup>5, 30, 32-34</sup>. This result also supports evidence that increasing EMG activations of spinal stability muscles is the mechanism used to meet increased respiratory demand<sup>7-10, 22, 24</sup>. An additional interesting finding is that % MVICs of abdominal muscles in the different breathing patterns were comparable to %MVICs

in a single bridging exercise and a ball bridge exercise<sup>19</sup>. All abdominal muscles demonstrated even higher % MVIC in RMET than in the single bridging exercise. % MVICs of TrA-IO and RA during RMET were higher than ball bridge exercise, too<sup>19</sup>. Further ratio comparisons with other studies could not be performed since they did not provide data of the ratio analysis among different task demands. Our second conclusion is that muscle reliance patterns of synergist ratios do not change as the task changes (Table 2). In each breathing pattern, TrA-IO/RA was the highest followed by TrA-IO/EO, and MF/ES was the lowest. The same muscle reliance pattern was also found in a healthy group in a forward reaching exercise<sup>3</sup>, a bridging exercise in the supine position<sup>19, 20</sup>, and a ball bridging exercise after spinal stability training<sup>20</sup>. Of particular note, a low back pain group also demonstrated a similar muscle reliance pattern in a forward reaching exercise<sup>3</sup>. However, the low back pain group showed a lower synergist ratio than the control group and higher activation of global muscles, RA and EO, even though the muscle reliance pattern was not different from the control group<sup>3</sup>. The reason for the increased activation of global muscles was the provision of high levels of intra-abdominal pressure for spinal, especially, segmental stability<sup>6</sup>. Our third conclusion is that the synergist ratio of extensor muscles among different breathing patterns stayed around 1. The synergist ratio of extensor muscles during bridging exercises was also around 1<sup>19, 35</sup>. Our present findings support evidence that all back muscles contribute in a similar way in different tasks and exercises<sup>19</sup>. Different from the extensor muscles, the synergist ratios of abdominal muscles were dependent on whether the task needed increased rotational or lateral stability<sup>19, 20</sup>.

The results of this study show consistent synergist ratios and muscle reliance patterns of spinal stability muscles even though the respiratory demands changed. Based on the results of this study and other studies, we consider that the contributions of the local and global abdominal muscle groups to spinal stability are independent of the demand of the task, but are dependent on the characteristics of the task. Different from abdominal muscles, the contributions of the local and global extensor group muscles were independent

of both task demands and characteristics. Therefore, exercises for spinal stability would be more effective if they focused on diversity of exercise type rather than simply changing task demands. Any pathologies like low back pain seem to change the contribution of local and global groups to spinal stability. Interestingly, the findings of this study were consistent with other studies in which spinal stability exercises were analyzed. In addition, an experimental group in spinal stability trainings demonstrated synergistic ratios similar to those of this study<sup>20</sup>. Therefore, we cautiously suggest the use of breathing patterns, especially RMET as a spinal stability exercise. During RMET, both local and global muscle groups showed muscle reliance patterns and synergist ratios similar to those of other spinal stability exercises. Also, both local and global muscles during RMET demonstrated activation levels comparable to other spinal stability exercises, and even show higher activations than in a ball bridge exercise. It has been suggested that exercises with appropriate synergistic relation between global and local muscle groups and sufficient muscle activation levels may be more suitable for spinal stability exercises<sup>5</sup>. Further investigations of synergist ratios of spinal stability muscles in different tasks and different patients groups, such as patients with low back pain, are required. In addition, future studies are needed to determine whether the % MVICs differences of spinal stability muscles in different breathing patterns are due to respiratory demand change or postural effects, especially in the case of the extensor muscles.

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